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# FOREIGN TECHNOLOGY DIVISION

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EFFECT OF VORTEX GENERATORS ON THE AERODYNAMIC WING CHARACTERISTICS AND BODY OF REVOLUTION

by

A.M. Mkhitaryan, S.A. Lukashuk, et al.



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| Block | Italic | Transliteration | Block | Italic | Transliteration |
|---|---|---|---|---|---|
| А а | *А а* | A, a | Р р | *Р р* | R, r |
| Б б | *Б б* | B, b | С с | *С с* | S, s |
| В в | *В в* | V, v | Т т | *Т т* | T, t |
| Г г | *Г г* | G, g | У у | *У у* | U, u |
| Д д | *Д д* | D, d | Ф ф | *Ф ф* | F, f |
| Е е | *Е е* | Ye, ye; E, e* | Х х | *Х х* | Kh, kh |
| Ж ж | *Ж ж* | Zh, zh | Ц ц | *Ц ц* | Ts, ts |
| З з | *З з* | Z, z | Ч ч | *Ч ч* | Ch, ch |
| И и | *И и* | I, i | Ш ш | *Ш ш* | Sh, sh |
| Й й | *Й й* | Y, y | Щ щ | *Щ щ* | Shch, shch |
| К к | *К к* | K, k | Ъ ъ | *Ъ ъ* | " |
| Л л | *Л л* | L, l | Ы ы | *Ы ы* | Y, y |
| М м | *М м* | M, m | Ь ь | *Ь ь* | ' |
| Н н | *Н н* | N, n | Э э | *Э э* | E, e |
| О о | *О о* | O, o | Ю ю | *Ю ю* | Yu, yu |
| П п | *П п* | P, p | Я я | *Я я* | Ya, ya |

*<u>ye</u> initially, after vowels, and after ъ, ь; <u>e</u> elsewhere.
When written as ё in Russian, transliterate as yё or ё.

## RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

| Russian | English | Russian | English | Russian | English |
|---|---|---|---|---|---|
| sin | sin | sh | sinh | arc sh | $\sinh^{-1}$ |
| cos | cos | ch | cosh | arc ch | $\cosh^{-1}$ |
| tg | tan | th | tanh | arc th | $\tanh^{-1}$ |
| ctg | cot | cth | coth | arc cth | $\coth^{-1}$ |
| sec | sec | sch | sech | arc sch | $\text{sech}^{-1}$ |
| cosec | csc | csch | csch | arc csch | $\text{csch}^{-1}$ |

| Russian | English |
|---|---|
| rot | curl |
| lg | log |

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Page 254.

# EFFECT OF VORTEX GENERATORS ON THE AERODYNAMIC WING CHARACTERISTICS AND BODY OF REVOLUTION.

A. M. Mkhitaryan, S. A. Lukashuk, V. D. Trubenok, V. Ya. Fridland

(Kiev)

The results are presented of experimental investigations of the effect of vortex generators on the aerodynamic characteristics of streamlined bodies. Qualitative results are obtained corrobating the possibility of stabilizing the intact flow over a wing at large angles of attack. The results of an experiment on the flow over bodies of revolution with vortex generators are presented.

Vortex generators, which are deepenings (cavity) in streamlined with fluid flow of rigid surface, attract attention already for 20 years.

Academician D. I. Blokhintsev [1] gave analysis of flow of ideal (inviscid) liquid in vortex generator and its vicinities. It is shown that the intensity of the vortex, which is incipient in the cavity, increases and vortex periodically will be carried by external flow downstream. The frequency of the generation of vortices can be sonic and ultrasonic. D. I. Blokhintsev investigated the phenomenon of the resonance, when the natural frequency of liquid within the cavity coincides with the frequency of the generation of vortices. On the basis of targets and tasks of his investigations, D. I. Blokhintsev called these cavities resonators. This name in essence was preserved also in the work of other authors, but their phenomenon of resonance interested already to a lesser degree. In the present work is

utilized the term "vortex generators", is more correctly, in our opinion, reflecting the essence of the phenomenon.

P. N. Kubanskiy [2, 3], utilizing vortex generators for intensification of heat exchange during flow of liquid about banks of tubes, revealed that under specific conditions hydrodynamic drag of banks of tubes with smooth surface proves to be greater than resistance of tubes with vortex generators, which were in experiments cylindrical deepenings, drilled in wall of tube.

Explanation of P. N. Kubanskiy, given to this strange is at first glance phenomenon, lies in the fact that vortices, generated by vortex generators, form "cylinders", on which slips boundary layer.

Page 255.

This reduces hydrodynamic drag of surface; however, energy additionally is expended on the vortex formation. Total effect can lead to reduction in hydrodynamic drag.

It is sufficiently in detail physics of phenomena, connected with flow around vortex generators, investigated by V. K. Migaem [4, 5], who studied experimentally flow pattern within vortex generators of different sizes, and also within plane diffuser with vortex generators and flow around cylindrical surface, placed in flat duct. He arrived at the conclusion that the intense turbulent mass exchange occurs between the liquid within the vortex generator and the external flow,

in consequence of which near the fairing the curve of speed is reconstructed, becoming more than "complete". This directed V. K. Migaya to the thought about the use of vortex generators for the stabilization of flows in the diffusers with the high downstream pressure gradients. For the cylindrical surface, in particular, they obtained the bias/displacement of separation point from 24 to 35-38°.

In laboratory of aerodynamics of Kiev Institute of engineers of civil aviation authors of this article checked conclusions V. K. Migaya and after their confirmation effect of vortex generators on boundary-layer flow under conditions of exterior problem is investigated. Experiments confirmed the possibility of the stabilization of the flow above the wing with high positive pressure gradient. Vortex generators made it possible to postpone the onset of the separation mode of flow and it is essential to increase thus the critical angle of attack of airfoil.

In process of blasting of finite-span wing established fact of reduction in effectiveness of vortex generators as a result of three-dimensional character of flow. Almost completely it was possible to reduce effect by location in the cavity of the vortex generators of separator partitions.

For practical purposes vortex generators most likely can be used on wings, equipped with flaps.

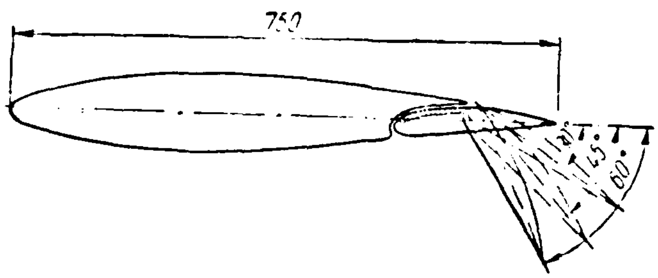


Fig. 1. Model of wing profile with flap for studying effect of vortex generators on effectiveness of flap.

Page 256.

In this case in the cruise setting the flap with the vortex generators is forced against wing (Fig. 1), vortex generators do not affect wing characteristics. In the takeoff and landing modes the flap is advanced back, being simultaneously turned down around its rotational axis, and vortex generators begin to flow itself by the flow, which penetrates through the slot between the wing and the flap.

For studying effect of vortex generators on effectiveness of flap two-dimensional experiment with airfoil with flap was carried out. Airfoil thickness $\bar{c}$=13%, chord b=750 mm, the chord of flap $b_з$=228 mm. On the upper surface of the flap of six sections interchangeable (Fig. 2), which gave the possibility to establish vortex generators in different places along the chord. Are investigated the vortex generators of two sizes: I type - 2.5×5 mm and II type - 3.5×7 mm (first numeral - width, the second - depth of the cavity of vortex generators).

Experiment was conducted at constant angle of attack of wing of $\alpha=10°$. The models of wing and flap were drained in the central cross section. Drain holes were provided for, also, in the sections with the vortex generators (two openings in each section). They were located on the bottom of cavity, since the previous experiments showed that in this place the pressure is equalized up to a pressure of in the external flow (curve of pressures takes the form of smooth, monotonic curve without the jumps and the explosions).

Drain holes with the aid of flexible rubber hoses were connected with tubes of battery 70-point panel of piezometers. The speed in the tube stood still by Pitot tube and was maintained order 39-40 m/s. Pressure and temperature in the working chamber constantly were recorded. The effectiveness of one or the other set of sections was determined by the comparison of values $C_y$ during the identical installations of the airfoil of flap for the flaps with the smooth surface and by the system of vortex generators. Values $C_y$ were determined by the measurement of the area of the curves of normal pressures on the surface of wing and flap.

First of all was blown model of system wing - flap in that form, in which they exist without vortex generators.

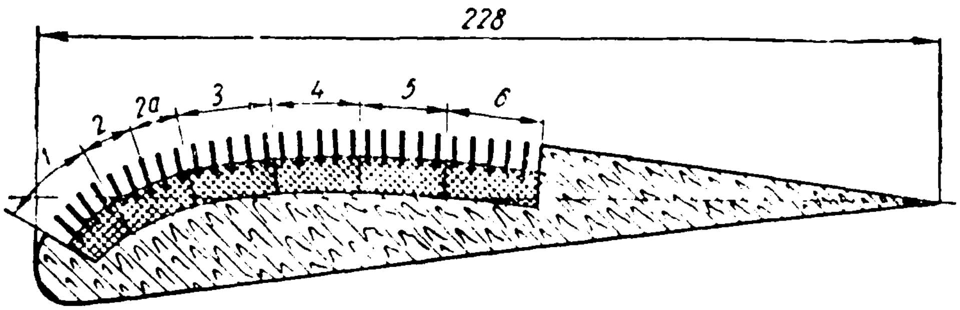


Fig. 2. Flap with plug-ins unit.

Page 257.

If the curve of nonseparated flow was obtained at the flap angle of $\delta$=30°, then at $\delta$=35 and 40° is already distinctly visible the zone of detached flow (according to the static pressure distribution). At $\delta$=45° breakaway began almost from the nose of flap. Two sections of vortex generators (second group of vortex generators) were established in the same mode, which led to the complete liquidation of breakaway. Let us note that the nonseparable character of flow was recorded by both the behavior of silk threads stuck on the surface of flap and by distribution of pressures over the surface of flap. Both methods give the coinciding results.

As a rule, installation of sections of vortex generators led to liquidation of breakaway on flap and respectively to increase in rarefaction above wing.

From analysis of summary charts (Fig. 3), where curves of dependences $\Delta C_y = f(\delta)$ for different types of vortex generators are

represented, it follows that their effectiveness in many respects depends on coordinate of beginning of region of ribbing. Consequently in order to attain maximum benefit from the installation of the system of vortex generators, necessary its coordinate began to be located somewhat higher than zone of probable flow breakaway. Until now the coordinate was determined by the empiricism (selection). It is clear that if it will be located too highly, i.e., in the convergent part, this will lead to braking of flow, which will sharply lower effectiveness, but if in the zone of deliberately detached flow, then vortex system will not be able to be conceived, since about vortex generators flow irregular slack flow with random inverse currents.

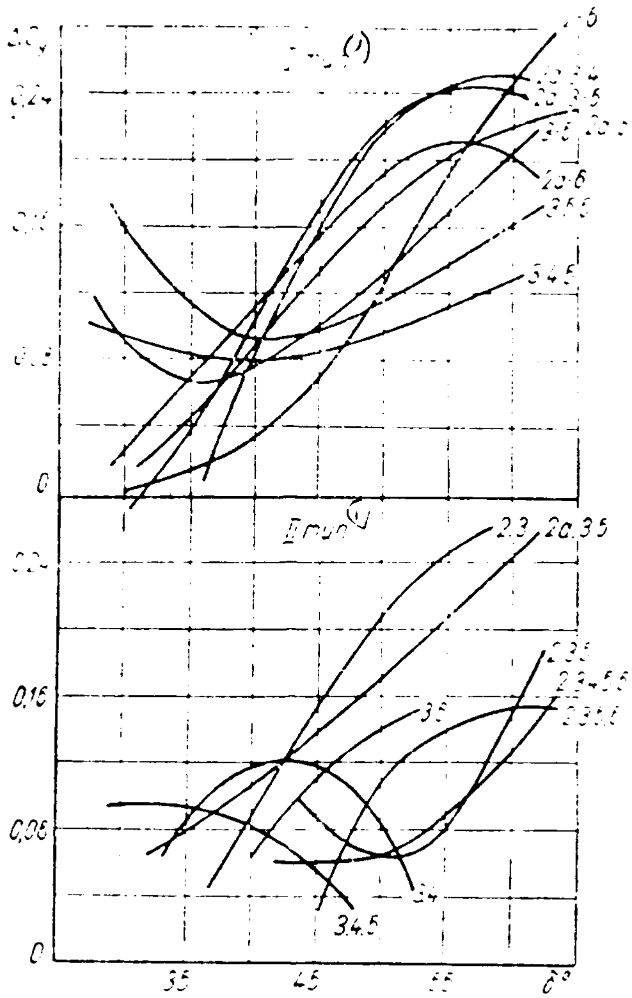


Fig. 3. Summary charts of dependences.

Key: (1). ... type.

Page 258.

Early beginning of ribbing (from second section) gives greatest effect at angles of deflection of δ=50-60°, more rear arrangement of first finned section (for example, the 3rd) makes it possible to obtain effect at δ=30-45°. Besides this, it is possible to fit the arrangement of ribbing, which would be "fully variable", i.e., it

would give a lift increment with the simultaneous liquidation of separation mode at all flap angles, which exceed 30°. They were not fulfilled for the smaller angles of measurement, since such modes are usually nonseparable, especially for the slotted flap.

In this case, apparently, will justify itself application of two series of vortex generators, when second series is located in zone of probable breakaway after first series, i.e., when between both series is section of smooth surface.

Being based on results of experiments, carried out earlier, to that given above it is possible to add that transverse sizes of vortex generators substantially do not change with change in geometric scale of model. The sizes of vortex generators depend mainly on the speed of the flow, which flows around about the vortex generators. One should expect that for the speeds of 40-60 m/s the optimum sizes will prove to be of the same order as those accepted in the experiment. The results of experiment should be considered faster as qualitative, than quantitative, since it was not model. This is explained by the fact that the sizes of model for the working section were overstated as a result of the need obtain the sufficiently large flap, on which it would be possible to place the vortex generators of necessary sizes and as it is more than as possible drain holes. Under these conditions entire air jet, which escapes from nozzle, was deflected/diverted by model.

One should expect that with observance of modeling regime of rarefaction on upper surface of wing and flap will be much greater than this is obtained in experiment; however, breakaway, possibly, will begin somewhat earlier. As a whole it is possible to assume a noticeable increase in the effectiveness of vortex generators.

Theoretical and experimental data confirm that during nonseparable and even flow of bodies airflow frictional resistance will be Meniere, if boundary-layer flow laminar, and vice versa, if turbulent flow is established with the same Reynolds numbers, then frictional resistance increases with increase in turbulence level.

Our experiments showed that it is possible to attain reduction in frictional resistance during turbulent boundary-layer flow. Reduction in the resistance is achieved by the creation of the local separation zones, in which the averaged speed substantially less than the speed in the external flow.

Page 259.

Local separation is created as a result of the flow around the vortex generators, which oriented it is perpendicular to external flow.

After vortex generator is formed vortex sheet, and therefore diagram of speed on surface of streamlined body (h=15 mm, b=10 mm, distance of 80 mm) transforms itself in such a way that on very body surface is characteristic for so-called stagnation zone section of low

speeds with small gradients of velocity (Fig. 4).

For checking position mentioned above was carried out weight experiment in wind tunnel for purpose of study of effect of vortex generators on drag data of bodies, which are located in airflow.

Subject of investigation selected body of revolution with diameter of 80 mm (Fig. 5), which ensured elimination of end effects. The model of body of revolution consists of nose, cylindrical and tail pieces. Nose section has spherical form. Length and conicity of tail piece of the body of revolution was selected in such a way that it would be possible to avoid the separation phenomena, especially with small Reynolds numbers.

On cylindrical part of body of revolution was arranged vortex generator, which was located from beginning of model at a distance of 80 mm. The speed of flow in the wind tunnel varied within the limits of 0-35 m/s.

Drag of body of revolution was measured with the aid of aerodynamic balances. The suspension of the model of body of revolution to the aerodynamic balances was accomplished with the aid of the string d=0.2 mm, which eliminated the effect of suspensions on the drag of body of revolution.

Coincidence of longitudinal axis of body of revolution and

direction of speed of flow was checked by measurement of lift with the aid of aerodynamic balances. In this case the lift was equal to zero.

According to results of experiment diagrams of dependence of drag coefficient of body of revolution on Reynolds number for varied conditions for flow were constructed (Fig. 6).

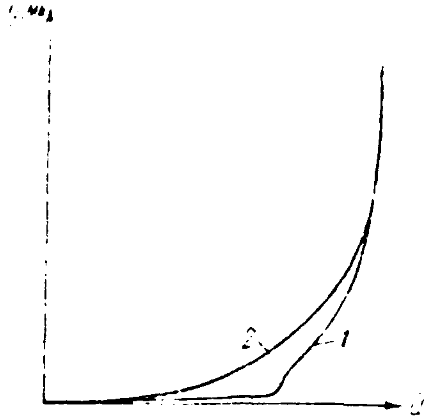

Fig. 4. Diagram of speed $y=f(\bar{u})$ for smooth surface of (1), after vortex generator (2).

Page 260.

Drag was determined for the model of body of revolution with the smooth surface, separately with the annular vortex generator d=0.4 mm and separately with the vortex generator with ratio h/b=1.5, where h - depth and b - width of vortex generator. Experiments regarding the drag were carried out also during the joint installation of annular vortex generator and vortex generator.

Comparison of drag coefficient of body of revolution with smooth surface also of drag coefficients with vortex generator and vortex generator indicates noticeable reduction or increase of drag coefficient in the latter case. In Fig. 6 it is shown that during the installation of annular vortex generator at a distance of 40 mm from the beginning of the cylindrical part of the body of revolution the drag will be more than resistance for the smooth surface with Reynolds

numbers $7 \cdot 10^5 - 1.3 \cdot 10^6$.

During simultaneous installation of annular vortex generator and vortex generator with Reynolds numbers $4 \cdot 10^5 - 10^6$ resistance sharply decreases in comparison with resistance for smooth surface and only with Reynolds numbers from $10^6$ to $1.3 \cdot 10^6$ resistance of body of revolution becomes temporarily more than for smooth surface.

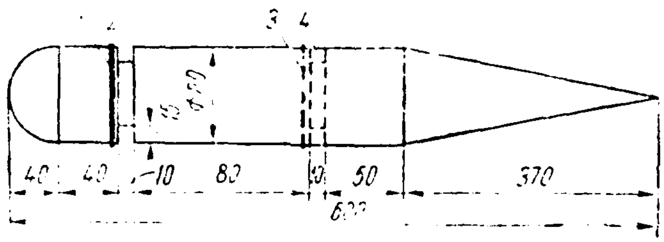


Fig. 5. Model of body of revolution with cylindrical form of nose section: 1 - vortex generator No. 1; 2 - vortex generator No. 1; 3 - vortex generator No. 2; 4 - vortex generator No. 2.

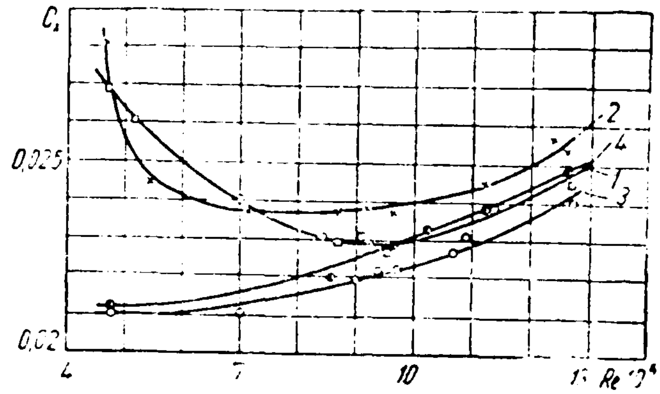


Fig. 6. Graph of dependence $C_x = f(Re)$: 1 - smooth surface; 2 - vortex generator No. 1: 3 - vortex generator No. 1; 4 - vortex generator No. 1 and vortex generator No. 1.

Page 261.

Resistance of body of revolution with vortex generator in entire range Reynolds number (from $4 \cdot 10^5 - 1.3 \cdot 10^6$) remains smaller in comparison with resistance of body of revolution with smooth surface, and is also less than during joint installation of vortex generator-vortex generator.

Fig. 7 gives results of experiments, carried out for very adverse conditions, when after first vortex generator at a distance of 80 mm annular vortex generator d=0.4 mm was located.

Presence of this vortex generator noticeably increased resistance of body of revolution (curve 1); however, during opening of vortex generator, located directly behind vortex generator, drag of body of revolution decreases approximately to initial.

For study of effect of sizes of vortex generator on drag model of body of revolution with length of 710 mm and with diameter of 80 mm with parabolic form of nose section was prepared. The design of vortex generator made it possible to change the width of the latter within limits of b/h=5-0.5, where b - width, h - depth of vortex generator is (h=const=5 mm). Vortex generator was established at a distance of 60 mm from the beginning of the cylindrical part of the body of revolution. The procedure of experiment is the same as for the first model.

Results of investigations are given in Fig. 8, where dependence of drag coefficient on Reynolds number and sizes of vortex generator is shown.

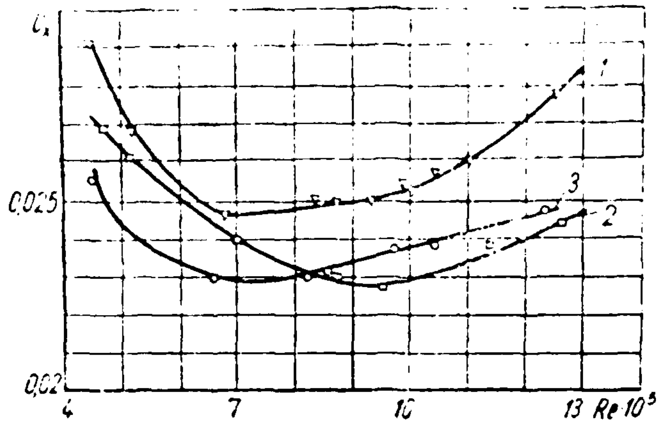


Fig. 7. Graph of dependence $C_x = f(\mathrm{Re})$: 1 - vortex generator No. 1 and vortex generator No. 2; 2 - smooth surface; 3 - vortex generator No. 1 and No. 2 and vortex generator No. 2.

Page 262.

With ratio b/h=5-3 and Reynolds numbers $4\cdot10^5$-$1.2\cdot10^6$ resistance of body of revolution with vortex generator is more than for smooth surface. The resistance of body of revolution with the vortex generator sharply decreases with ratio b/h=2.5-2 and Reynolds numbers $4\cdot10^5$-$8\cdot10^5$ and it becomes less than for the smooth surface, and only with large Reynolds numbers resistance becomes greater than for the smooth surface.

Resistance of body of revolution with vortex generators, whose relative sizes b/h=1.5-0.5, proved to be smaller than for smooth surface with entire range Reynolds number.

Smallest resistance of body of revolution proved to be with

relative size of vortex generator b/h=0.8. With further decrease of b/h the resistance of body of revolution with the vortex generator increased.

Fig. 9 gives dependence of increment in drag coefficient on relative size of b/h for Reynolds's different.

Analyzing obtained dependences, it is possible to show that with increase in relative size of b/h increment in drag coefficient decreases.

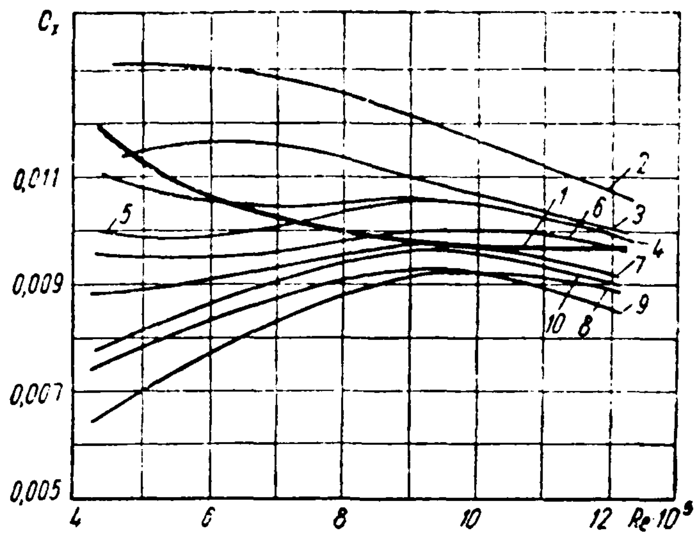


Fig. 8. Graph of dependence $C_x=f(\mathrm{Re}, \frac{b}{h})$: 1 - smooth body surface of rotation; 2 - vortex generator b/h=5 (h=5 mm); 3 - b/h=4; 4 - b/h=3; 5 - b/h=2.5; 6 - b/h=2; 7 - b/h=1.5; 8 - b/h=1.0; 9 - b/h=0.8: 10 - b/h=0.5.

Page 263.

Maximum gain in the drag coefficient is achieved at b/h=0.8 in the range Reynolds number $4\cdot10^5$-$1.2\cdot10^6$. With small Reynolds numbers ($4\cdot10^5$-$8\cdot10^5$) an increment in the drag coefficient is more intense than for Reynolds number from $8\cdot10^5$ to $1.2\cdot10^6$.

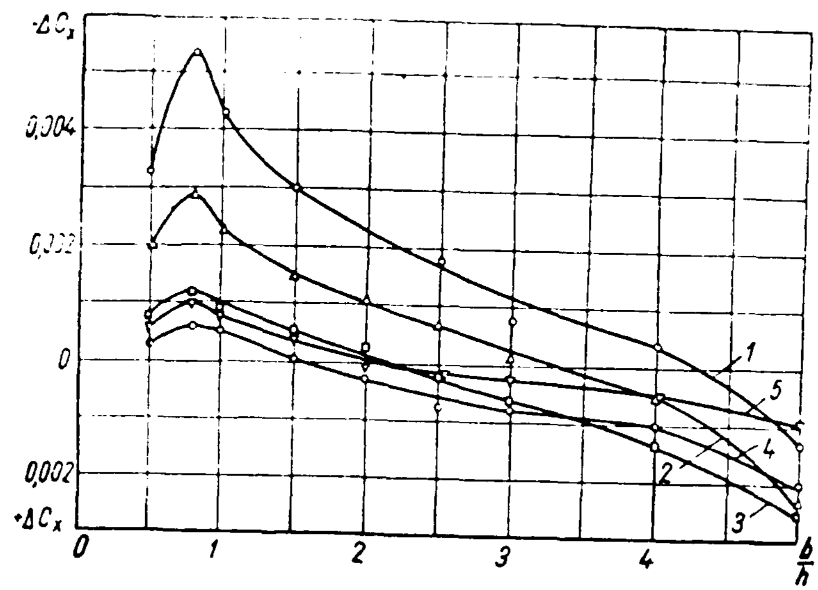


Fig. 9. Graph of dependence $\Delta C_x = f(Re, \frac{b}{h})$: 1 - Re=4.4•10⁵; 2 - 6•10⁵; 3 - 8•10⁵; 4 - 10⁶; 5 - 1.2•10⁶.

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